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Environmental Technology Cost-Savings Analysis Project

Estimating Heel Retrieval Costs for Underground Storage Tank Waste at Hanford

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Title: **_Estimating Heel Retrieval Costs for Underground Storage Tank Waste at Hanford_**

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A Cost Study Funded by the Department of Energy
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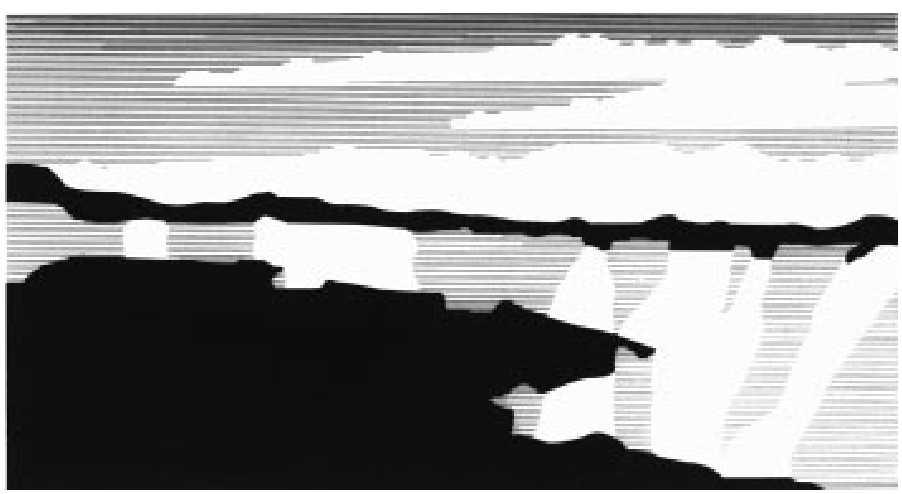
Tank Focus Area



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Conclusions

This study was performed in preparation of a comprehensive System Model to estimate costs related to the use of nonbaseline technologies for the remediation of underground storage tank (UST) waste across the DOE complex. Investigation of the UST heel retrieval cost at Hanford was selected for the initial model application. The cost of achieving 99% retrieval from USTs at the Hanford Site was estimated as a function of retrieval rate rather than specific retrieval technologies. Retrieval cost estimation for specific technologies can be made from the results of this study once the retrieval rate is known.

Within the range of heel retrieval rates and capital costs considered in this study the additional cost of retrieving 99% of the UST waste at Hanford, versus the baseline past practice sluicing (PPS) for single-shell tanks (SSTs) and mixer pumps (MPs) for double-shell tanks (DSTs), is $2.2 billion to $4.8 billion. It has been assumed for this study that PPS is capable of retrieving only 85% of the SST waste (Reference 1), and MPs are capable of retrieving only 90% of the DST waste (Reference 2). Figure 1 displays the heel retrieval costs for conditions considered in this study. The minimum heel retrieval rate considered for this study was one-quarter of the conventional PPS rate for SSTs, and one half of the conventional PPS rate for DSTs. The maximum heel retrieval rate considered was one half of the conventional PPS rate for SSTs, and equal to the conventional PPS rate for DSTs. The minimum additional capital cost considered was $1 million per tank and the maximum was $10 million per tank, with no additional infrastructure capital costs. The range of retrieval rate and capital cost was selected to provide a reasonable initial point-of-reference, but not suggest technology limits.

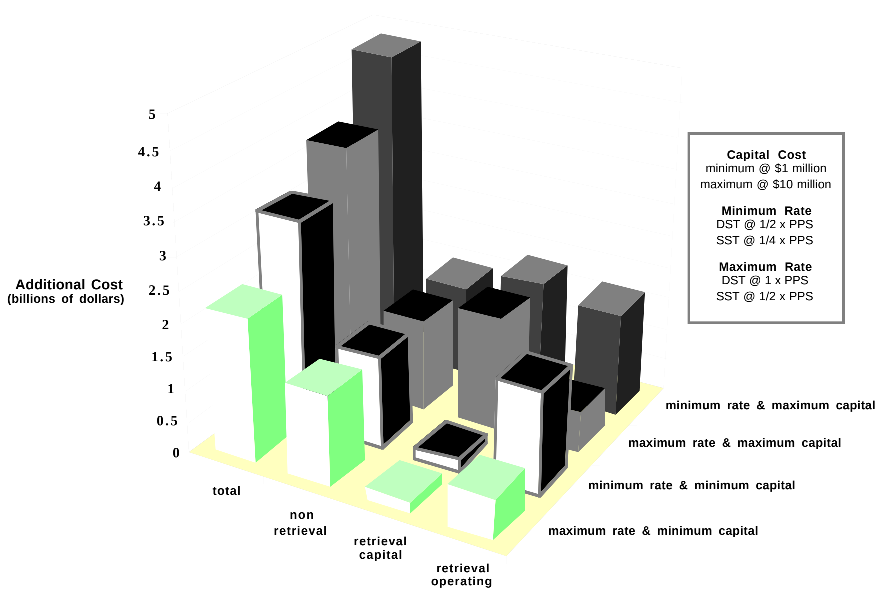


Figure 1. Beyond baseline costs for Hanford tank closure at 99% retrieval.

This effort was intended to lead to further studies based on cost and performance (i.e., retrieval rate) data for specific heel retrieval technologies. Assumptions were made to greatly simplify the retrieval scenarios for this effort. These assumptions have been clearly stated so that the conclusions can be viewed in their context.

Background

Approximately 100 million gallons (~400,000 m^3) of existing U.S. Department of Energy (DOE)-owned radioactive waste stored in USTs can not be directly disposed of as low-level waste (LLW). Disposal of LLW generally can be done sub-surface at the point of origin. Disposal of high-level waste (HLW), generally must be done in deep underground repositories. Consequently, LLW is significantly less expensive to dispose of than HLW. Due to the lower cost for LLW disposal, it is advantageous to separate the 100 million gallons of waste into a small volume of HLW and a large volume of LLW. Figure 2 shows the sites at which this waste is located, and their relative volumes and activities (i.e. curies).

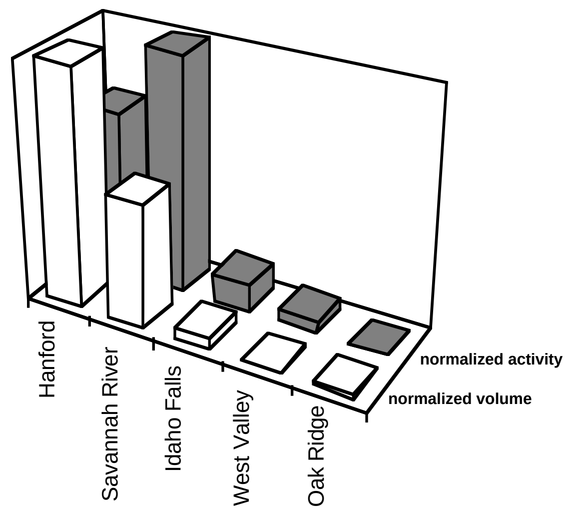


Figure 2. Underground storage tank waste volume and activity at each site (References 3 & 4).

Of the 100 million gallons of waste stored in USTs, approximately 65 million is located at the Hanford Site. The waste at Hanford is stored in SSTs and DSTs. Neutralization was performed on the initial acidic liquid waste to provide compatibility with the carbon steel USTs. Following neutralization, a sludge-like precipitant formed which settled on the bottom of USTs. In addition to the sludge, volume reduction of the neutralized liquid by evaporation created a crystalline-like material referred to as salt cake, and a pre-salt cake condition referred to as slurry. Most of the SST liquid waste remaining after neutralization and evaporation has been pumped into the DSTs, due to the SST reputation for leaking. PPS is the baseline technology for retrieving the remaining sludge and salt cake from the SSTs at Hanford. The baseline technology for retrieval of DST waste at Hanford is MPs.

Applicability

Significant quantities of waste in underground tanks currently exists at four DOE sites: (1) Hanford, (2) Savannah River, (3) Idaho Falls, and (4) Oak Ridge. Figure 3 shows the distribution of waste in USTs throughout the DOE complex.

Due to the large portion of DOE waste which is currently located at Hanford, it was chosen as the site for this study. However, the modeling used for this study is applicable to the other sites as well.

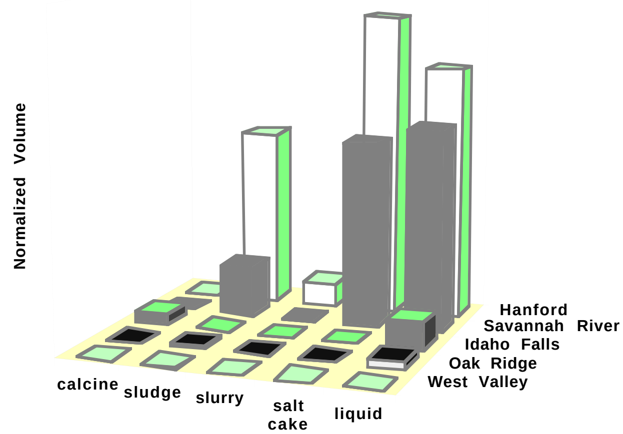


Figure 3. Forms of UST waste at each DOE site (References 3 & 4).

Assumptions

General

- » All costs are approximated as 1995 dollars.
- » Pretreatment, immobilization, and disposal unit operation costs are based on the Tri-Party Agreement (TPA) Alternative Engineering Data Package for the Tank Waste Remediation System Environmental Impact Statement (TWRS EIS), (Reference 5, Table F-36).
- » Retrieval costs are based on the TPA, Case Beta (Reference 6).
- » Waste processing flowsheet material balances are based on TWRS Flowsheet (Reference 1, Figures 2-3).
- » Waste type and volume for each tank are based on UST-ID Site Characteristics (Reference 4, Table A-1).

Retrieval

» SSTs will be retrieved by PPS with transfer pumps

- the sluicing rate will average 14.4 m^3/day (TWRS Flowsheet, Appendix B)
- the sluicing is rate limiting rather than the transfer pump rate

» DSTs will be retrieved by MPs with transfer pumps

- initial immobilization prior to transfer will average 200 hr/tank (TWRS Flowsheet, Section 5.2.1)
- the transfer pump will be rate limiting following immobilization at 75 gal/min (rate at Savannah River Site per Reference 2)

» Capital Cost

- total capital cost for retrieval is $5.1 billion (Reference 6, Case Beta)
- capital cost for retrieval per tank is simply the total site capital cost for retrieval divided by the number of tanks to be retrieved, since most of the retrieval cost is in infrastructure
  - mixer pumps cost ~ $1 million
  - sluicing equipment is similar in cost or less than mixer pumps
  - transfer pumps are included in the infrastructure

» Operating Cost

- total operating cost for retrieval is $3.7 billion (Reference 6, Case Beta)
  - the cost per operating hour is based on $3.7 billion for retrieval of all 177 tanks (SST & DST)
  - equipment availability is 50% (similar to TWRS Flowsheet)

Pretreatment/Disposal

» Radionuclide Separation

- ion-exchange-resin performance is based on the TWRS Flowsheet
- costs are based on Reference 5, Table F-36

» Nonradionuclide Separation

- sludge wash performance is based on TWRS Flowsheet
- costs are based on Reference 5, Table F-36

» HLW & LLW Immobilization

- glass loading is based on TWRS Flowsheet
- costs are based on Reference 5, Table F-36

» LLW Disposal

- costs are based on Reference 5, Table F-36

» HLW Interim Storage and Disposal

- costs are based on Reference 5, Table F-36

Caveats

This analysis was funded by the Department of Energy, Office of Science and Technology (DOE/EM-50), specifically the Tank Focus Area (TFA). The conclusions are not necessarily those of the funding agency or Los Alamos National Laboratory. This is a scoping study not a detailed analysis and as such, is not intended to represent the only method for calculating costs.

Analysis/Results

Figure 4 represents a generic processing flowsheet for waste remediation across the DOE complex. Specifically, the material balances of Figure 4 represent the TWRS Flowsheet. The referenced stream numbers relate directly to those of Figures 2-3 of the TWRS Flowsheet. The material amounts shown in Figure 4 represent only the portion of tank waste which is incorporated in the final LLW or HLW forms. These components, which are incorporated in the final waste forms, are primarily aluminum, iron, chromium, sodium, and phosphorus. Those which are not incorporated in the final waste form include nitrate, nitrite, and water.

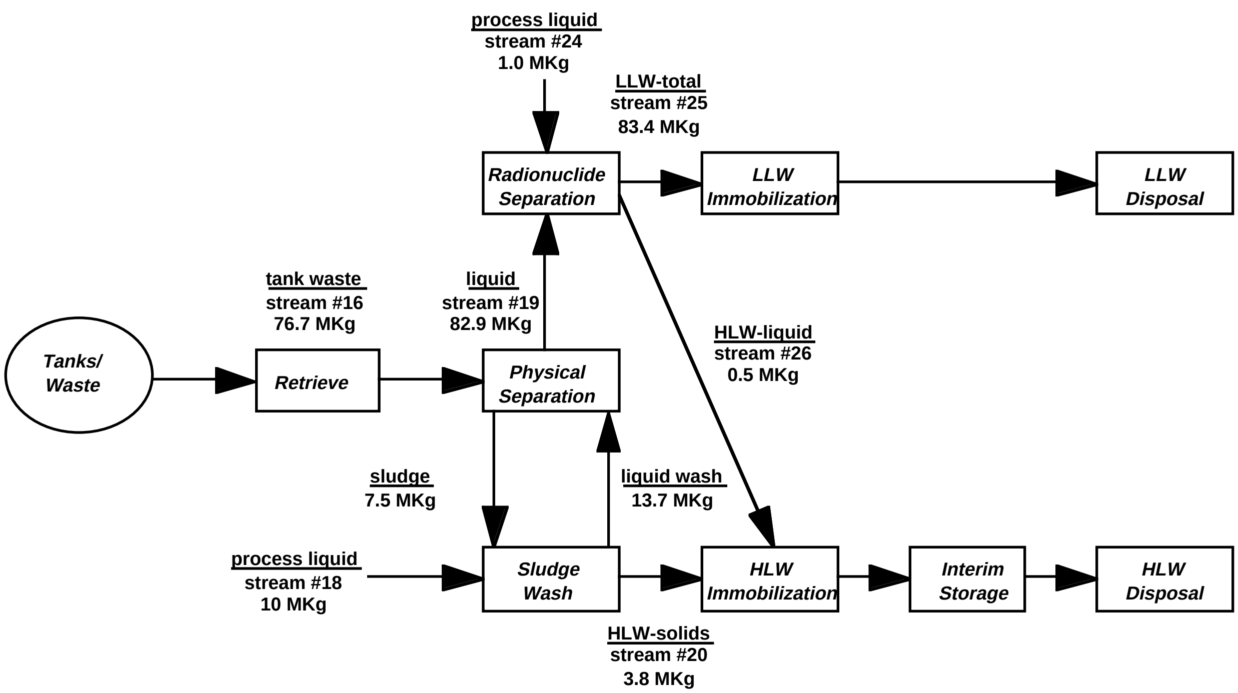


Figure 4. Material balances for Hanford TWRS.

The material amount for each stream shown in Figure 4 was determined directly from the TWRS Flowsheet with the exception of the (1) Sludge Wash and (2) Liquid Wash. Figure 5 shows the characteristics of the Sludge Wash defined by the TWRS Flowsheet. These characteristics were used to determine the material amount for the Sludge and Liquid Wash streams as follows.

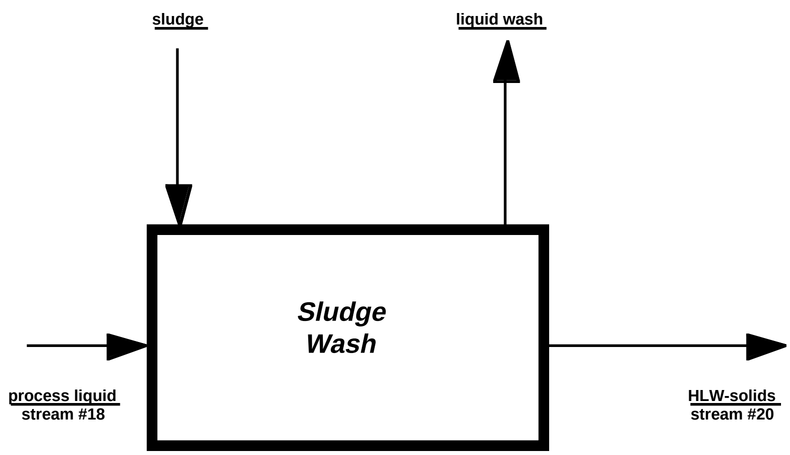
Sludge

Al	1.190 Mkg/(1-0.68)	=	3.719 Mkg
Fe	0.752 Mkg/(1-0.00)	=	0.752 Mkg
Cr	0.054 Mkg/(1-0.64)	=	0.150 Mkg
Na	1.670 Mkg/(1-0.25)	=	2.227 Mkg
P	0.164 Mkg/(1-0.74)	=	0.632 Mkg
Total			7.480 Mkg

Liquid Wash

Al	(3.719 - 1.190) Mkg	=	2.529 Mkg
Fe	(0.752 - 0.752) Mkg	=	0
Cr	(0.150 - 0.054) Mkg	=	0.096 Mkg
Na	[(2.227 - 1.670) + 10] Mkg	=	10.557 Mkg
P	(0.631 - 0.164) Mkg	=	0.468 Mkg
Total			13.650 Mkg

The sodium in the Liquid Wash includes 10 Mkg from the process liquid, stream #18.



component	MKg
Na	10.0

component	MKg	wash efficiency(%)
Al	1.190	68
Fe	0.752	0
Cr	0.054	64
Na	1.670	25
P	0.164	74
total	3.830	

Figure 5. Sludge Wash characteristics.

The costs shown in Figure 6 were derived from Table F-36 of Reference 5, and Figure 4 of this document.

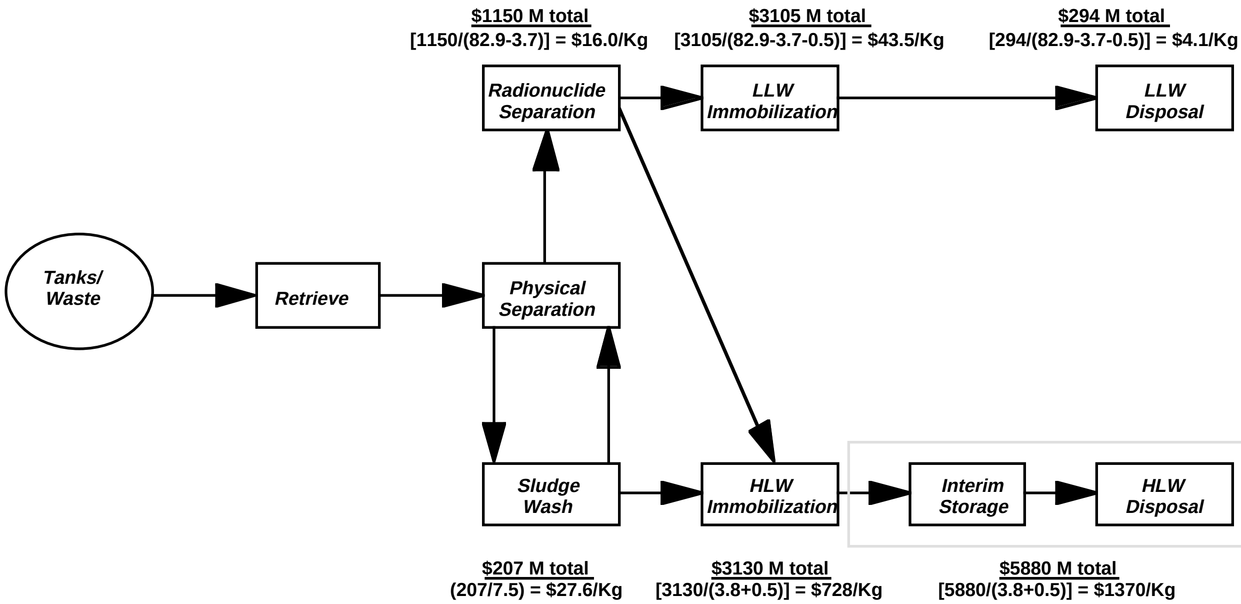


Figure 6. Processing costs for TWRS.

Table F-36 is reproduced in Table 1 of this document, and used as follows to determine the processing costs for Figure 6.

Radionuclide Separation	=	[cesium removal + (1/3)(central facilities)]
Sludge Wash	=	sludge wash
LLW Immobilization	=	[LLW vitrification + (1/3)(central facilities)]
LLW Disposal	=	LLW disposal
HLW Immobilization	=	[HLW vitrification + (1/3)(central facilities)]
Interim Storage	=	included in HLW disposal box
HLW Disposal	=	(HLW transportation + HLW disposal)

Table 1. Hanford remediation costs.

	Cost ($ millions)
Sludge Wash	207
Cesium Removal	975
Centralized Facilities	520
LLW Vitrification	2934
LLW Disposal	294
HLW Vitrification	2957
HLW Transportation	24
HLW Disposal	5858

Figure 7 shows the TWRS remediated distribution of waste for each waste type. For instance, the HLW-solids stream of Figure 7 is generated from only sludge-based tank waste; whereas, the LLW-total and HLW-liquid streams are generated from both liquid-based and sludge-based tank waste. The liquid-based tank waste is comprised of supernate, salt cake, and slurry. The contributions are based on the relative amounts of each stream.

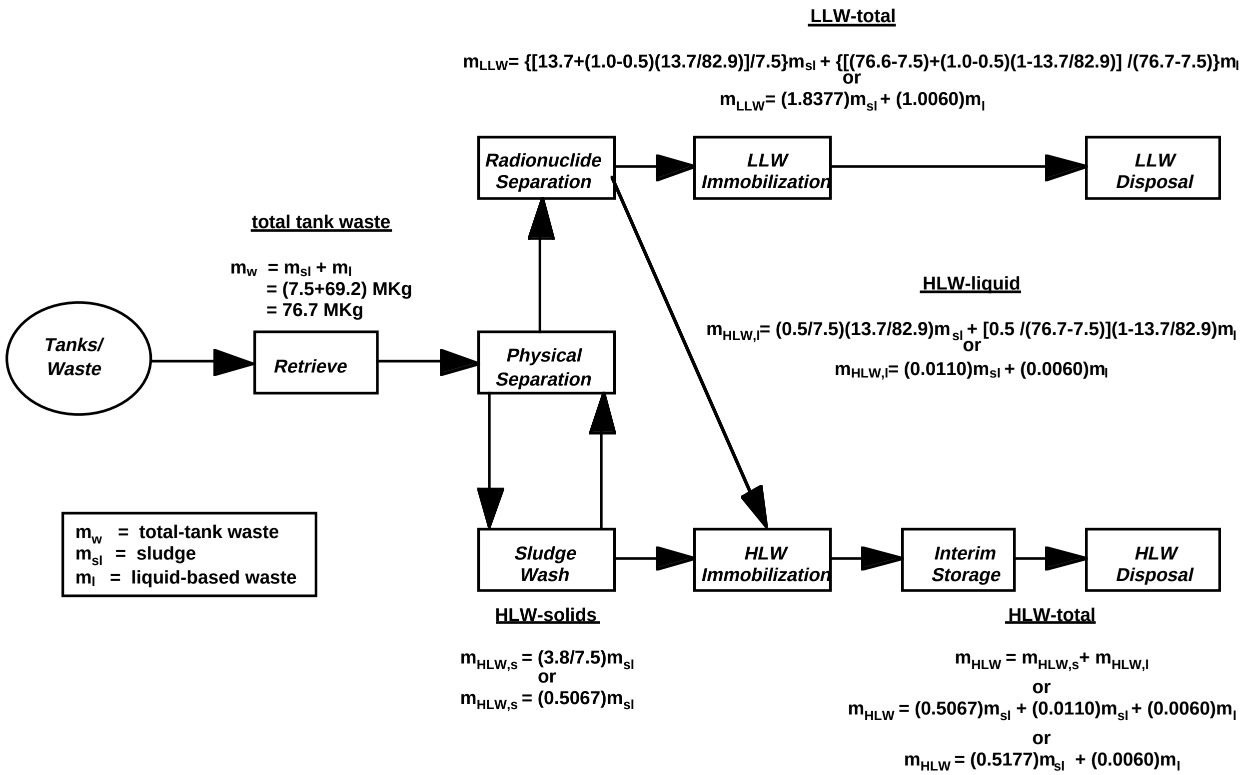


Figure 7. Simplified material distribution model for TWRS.

The method for calculating the remediation cost for each individual tank at Hanford is based on the type and amount of waste in each tank as determined from Table A-1 of Reference 4. The remediation cost for SST-S107 and DST-SY101 are used as examples for this study. Retrieval costs are estimated for both tanks S107 and SY101 to demonstrate differences in SSTs and DSTs; whereas, treatment and disposal costs were estimated only for S107 because the approach is identical for SSTs and DSTs. Table 2 reproduces the information in Table A-1 regarding S107 and SY101.

Table 2. Waste types for Hanford Tanks S107 and SY101.

Tank	Supernate (1000 gallons)	Salt Cake (1000 gallons)	Sludge (1000 gallons)	Slurry* (1000 gallons)
S107	6	69	293	0
SY101	29	560	0	530

*slurry definition per Reference 6, supernate concentrated almost to point of crystallization

Table 3 is derived from Tables 4-10 of Reference 4, and shows the average concentration of the most significant waste components requiring final disposal for each type of tank waste. These components are typed bold-faced and in italics.

Table 3. Final waste-form components.

	Liquid (wt %)	Salt Cake (wt %)	Slurry* (wt %)
$NaNO_3$	20.8	81.5	14.8
- Na	***5.6***	***22.1***	***4.0***
$NaNO_2$	15.8	1.7	5.6
- Na	***5.3***	***0.6***	***1.9***
Na_2CO_3	0.6	0.5	1.9
- Na	***0.3***	***0.2***	***0.8***
NaOH	6.2	1.5	7.0
- Na	***3.6***	***0.9***	***4.0***
$NaAlO_2$	12.5	1.4	5.6
- Na	***3.5***	***0.4***	***1.6***
- Al	***1.2***	***0.1***	***0.5***
Na_3PO_4	2.3	0.6	0.8
- Na	***1.0***	***0.7***	***0.3***
- P	***0.4***	***0.1***	--
Na_2SO_4	--	1.3	0.3
- Na	--	***0.4***	***0.1***
- S	--	***0.3***	***0.1***
FeO(OH)	--	--	0.2
- Fe	--	--	***0.2***
$Al(OH)_3$	--	--	4.9
- Al	--	--	***1.7***
Na_2CrO_4	1.3	--	--
- Na	***0.4***	--	--
- Cr	***0.4***	--	--
Total	***21.7***	***25.8***	***15.2***

*see definition for Table 2

The average density of each waste type, with regard to ***only the most significant components present in the final waste form***, can then be calculated from (1) the volume of each waste type listed in Reference 4 and (2) the waste mass from the TWRS Flowsheet, as follows.

Sludge-based disposed-waste density

disposed-waste mass (Figure 4) = 7.5 Mkg

total volume (Reference 4, Table A-1) = 14.4 Mgal

disposed-waste density (d_{sg}) = 7.5 Mkg/14.4 Mgal = 0.521 kg/gal (135 kg/m^3)

Note: It is likely the sludge volume of Reference 4 includes a significant quantity of interstitial liquid which lowers the concentration of disposed components.

Liquid-based disposed-waste density			Liquid-based disposed-waste volume		
supernate	=	d_{su}	supernate	=	v_{su}
salt cake	=	d_{sc}	salt cake	=	v_{sc}
slurry	=	d_{sl}	slurry	=	v_{sl}

$(v_{su})(d_{su}) + (v_{sc})(d_{sc}) + (v_{sl})(d_{sl}) = 69.2$ Mkg [Figure 4; tank waste(76.7) - sludge(7.5) = 69.2]

from Table 3

$(d_{sc})/(d_{su}) = 25.8/21.7 = 1.19$

$(d_{sl})/(d_{su}) = 15.2/21.7 = 0.70$

from Reference 4, Table A-1

v_{su} =19.7 Mgal

v_{sc} = 24.2 Mgal

v_{sl} = 2.0 Mgal

rearranging and solving yields

$d_{su} = 69.2 \text{ Mkg}/(v_{su} + 1.19v_{sc} + 0.70v_{sl})$

d_{su} = 1.39 kg/gal (358 kg/m^3)

d_{sc} = 1.65 kg/gal (418 kg/m^3)

d_{sl} = 0.97 kg/gal (247 kg/m^3)

The processing and disposal costs for each tank can now be calculated based on Figure 6 and Figure 7, and demonstrated for Tank S107.

Masses

disposed-waste (Table 2)

supernate: (6000 gal)(1.39 kg/gal) = 8340 kg

sludge: (293,000 gal)(0.521 kg/gal) = 153,000 kg

salt cake: (69,000 gal)(1.65 kg/gal) = 114,000 kg

m_{LLW} = 1.8377(153,000 kg) + 1.0060(8340+114,000) kg = 404,000 kg

$m_{HLW,l}$ = 0.0110(153,000 kg) + 0.0060(8340+114,000) kg = 2400 kg

m_{HLW} = 0.5067(153,000 kg) + 0.0060(8340+114,000) kg = 78,300 kg

Costs

Radionuclide Separation	[(404,000+2400)kg]($16.0/kg)	= $6.5 M
Sludge Wash	(153,000 kg)($27.6/kg)	= $4.2 M
LLW Immobilization	404,000 kg($43.5/kg)	= $17.6 M
HLW Immobilization	78,300 kg($728/kg)	= $57.0 M
LLW Disposal	404,000 kg($4.1/kg)	= $1.7 M
HLW Storage/Disposal	78,300 kg($1370/kg)	=$107.3 M

Table 4 summarizes the processing and disposal costs for Tank S107.

Table 4. Summary of processing and disposal costs.

Tank	Pretreatment ($ millions)	LLW ($ millions)	HLW ($ millions)
S107	6.5 + 4.2 = 10.7	17.6 + 1.7 =19.3	57 + 107 = 164

The retrieval cost for each tank can be calculated from the volume of each waste type as shown for SST-S107 and DST-SY101.

Capital Cost

(identical for both SST and DST since most of cost is in waste transfer infrastructure)

($5100 M/177 tanks) = $29 M/tank (from TPA, Reference 6)

Operating Cost

SST (see Assumptions section)

Tank S107

Operating Time

(14.4 m3/day or 1.3 Mgal/yr) at 50% availability

(293,000 + 69,000)gal = 362,000 gal

supernate is removed with the transfer pump; and consequently, is insignificant with regard to retrieval operating time

[362,000 gal(1-Mgal/10^6 gal)]/[0.5(1.3 Mgal/yr)] = 0.56 yr

Rate Cost (iterative procedure)

(operating cost)Σ (operating time for Tank_i) = $3700 M (from TPA, Reference 6)

or

operating cost = ($3700 M) /$\Sigma$ (operating time for Tank_i)

where i = 1 to 177 (i.e., total number of tanks)

operating cost = $68 M/yr (from System Model)

Operating Cost

0.56 yr($68 M/yr) = $38 M

DST (see Assumptions section)

Tank SY101

Operating Time

200 hr + [(75 gal/min or 39 Mgal/yr) at 50% availability]

(29,000 + 560,000 + 530,000)gal = 1.19 Mgal

200 hr(1 yr/8760 hr) + 1.19 Mgal/[0.5(39 Mgal/yr)] = 0.08 yr

Rate Cost (same iterative procedure as for SST-S107)

Operating Cost

0.08 yr($68 M/yr) = $5.4 M

The total remediation costs for Tank S107 are shown below in Table 5.

Table 5. Total remediation costs for Tank S107.

Retrieval ($ millions)	Pretreatment ($ millions)	LLW ($ millions)	HLW ($ millions)	Total ($ millions)
29 + 38 = 67	6.5 + 4.2 = 10.7	17.6 + 1.7 =19.3	57 + 107 = 164	261

Figure 8 through Figure 10 display the remediation cost for each tank based on the TWRS Flowsheet and estimated as done for Tanks SY101 and S107. The Appendix relates tank numbers from Figures 8-10 to the actual Hanford tank numbers of Reference 4.

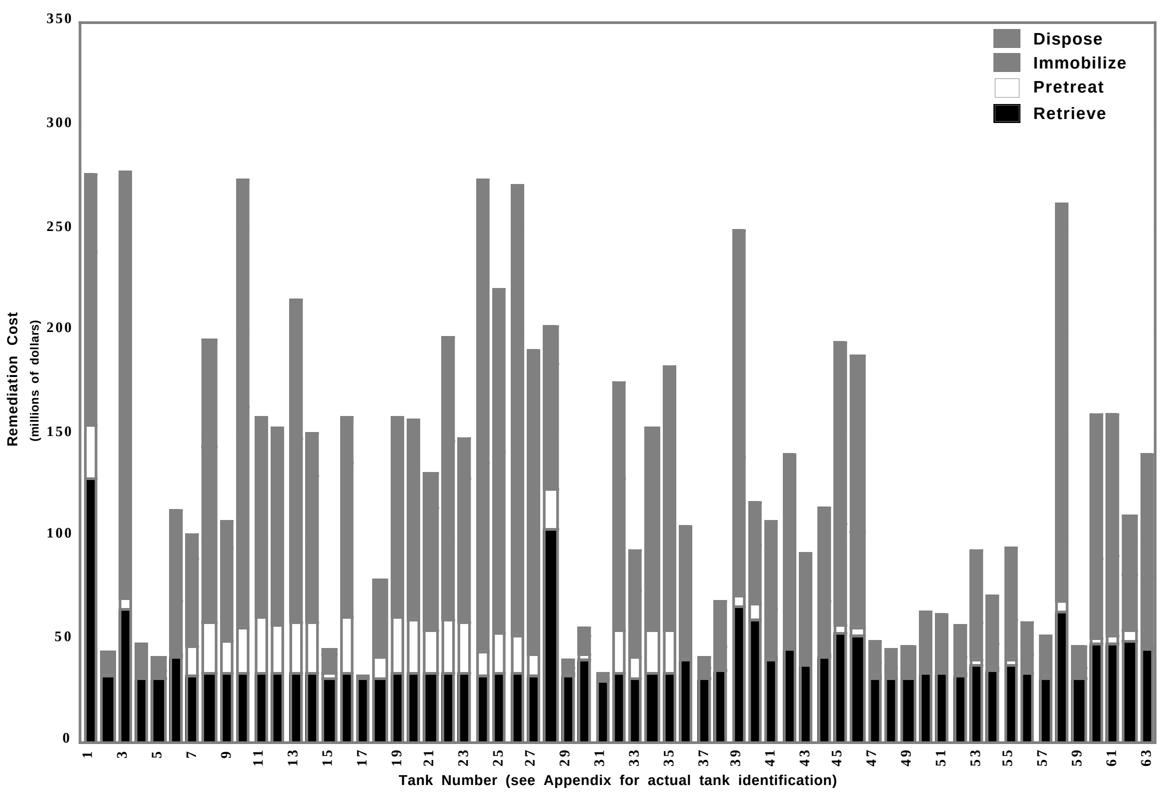


Figure 8. Remediation cost for Tanks A101-BX112.

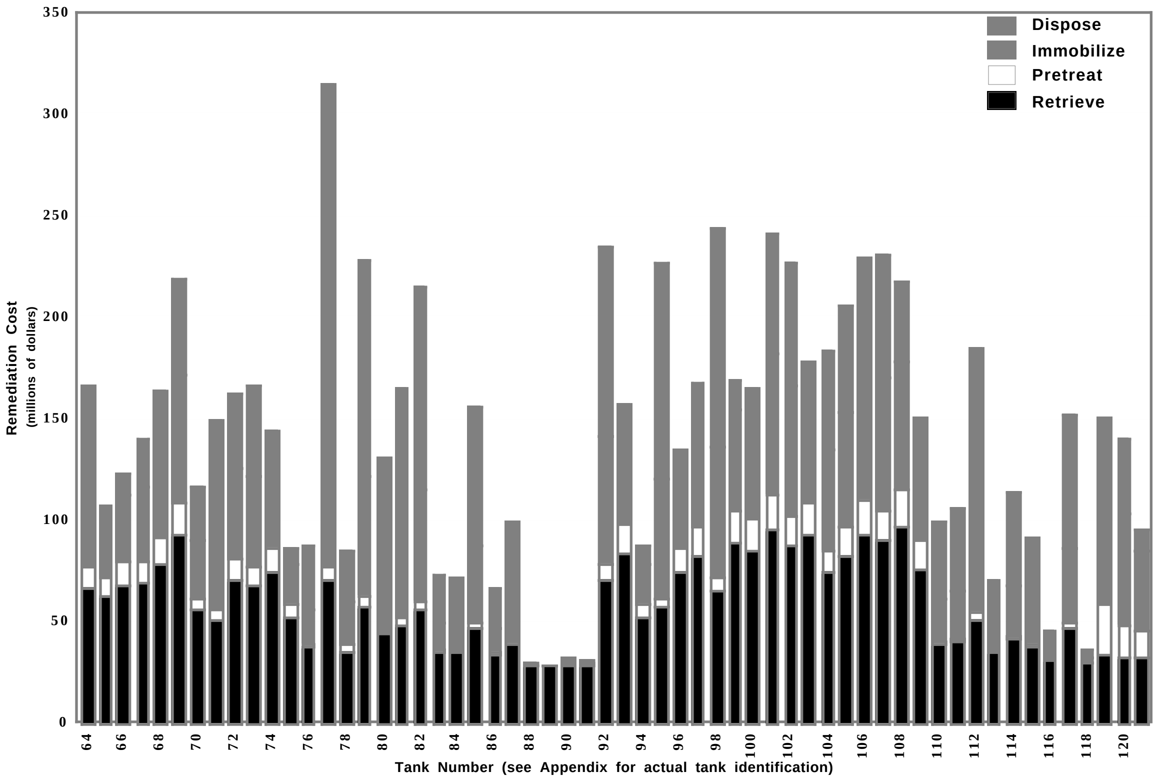


Figure 9. Remediation cost for Tanks BY101-SY103.

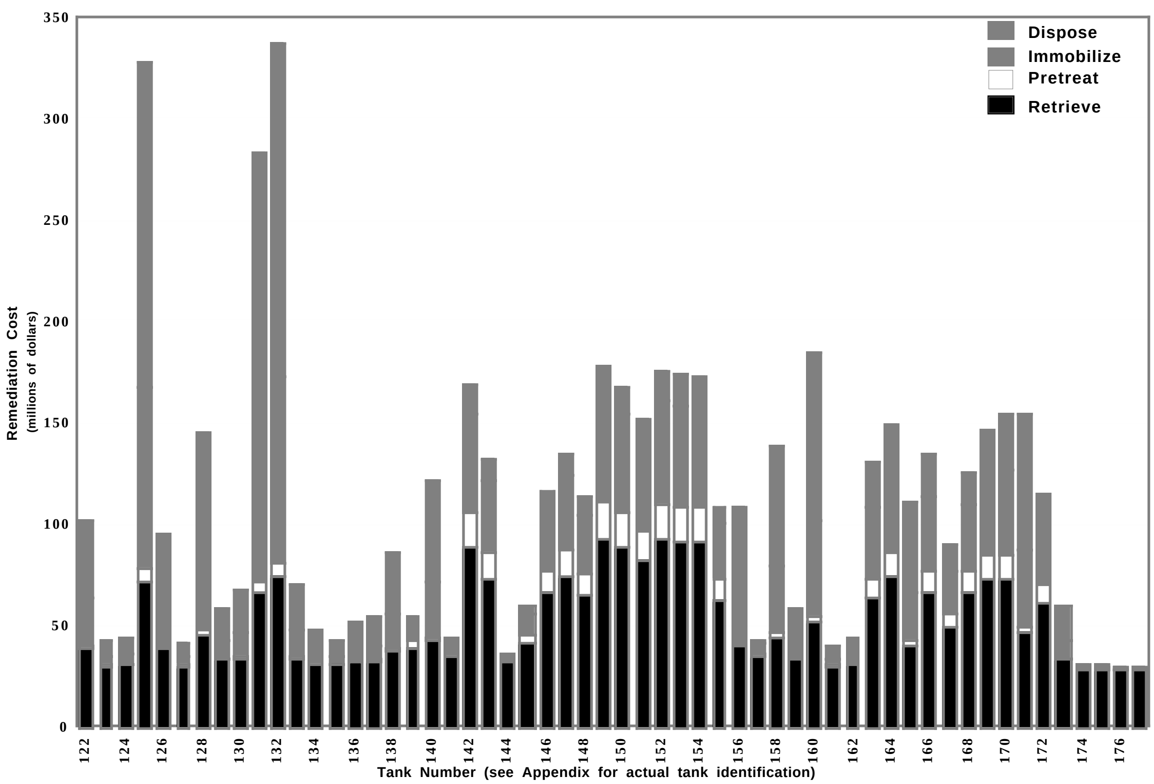


Figure 10. Remediation cost for Tanks T101-U204.

As long as the volume of each waste type (i.e. sludge, salt cake, etc.) for each tank totals the volume used to determine the (1) sludge-based disposed-waste density and (2) liquid-based disposed-waste densities, the System Model is self-normalizing and the remediation costs will equal those of the TPA.

The cost of retrieving heel was estimated by determining the retrieval, processing, and disposal costs for 14% of the SST waste and 9% of the DST waste. This is based on the following:

[99% (TPA guidance) - 85% (TWRS baseline)] = 14% for SST
[99% (TPA guidance) - 90% (Reference 2)] = 9% for DST

It assumes that the relative composition of waste types (i.e. sludge, salt cake, etc.) in the heel of each tank is similar to the overall contents. While this is not completely true, and in fact the heel has a higher percentage of sludge than the overall contents, this assumption allows an estimate of the heel retrieval cost for tanks with little sludge. This is important since PPS and MP tank retrieval is controlled by the shape of the tank bottom as well as the waste type. Heel retrieval costs for Tank S107 were estimated as follows.

Processing and disposal
0.14(11+19+164) = $27 M
Retrieval (operating only)
0.14[4(38)] = $21 M   minimum rate at (1/4)-PPS
0.14[2(38)] = $11 M   maximum rate at (1/2)-PPS

Capital costs were estimated to range from $1 million to $10 million per tank, assuming infrastructure costs were negligible due to use of the existing system. Current PPS systems cost approximately $1 million and it is assumed that systems ten-times more costly would significantly enhance the PPS retrieval rate.

The heel retrieval costs shown above were determined for each tank at Hanford, and were used to construct Figure 1 of this document. While the TPA remediation costs are based upon complete removal of tank waste, and in fact the TWRS baseline technology will only remove 85% of SST waste and 90% of DST waste; due to the approximate nature of the TPA cost estimates, it was felt that the 10-15% error introduced by such an approximation was well worth the modeling simplicity. There are many areas of the Systems Model developed for this study which can be improved upon with additional effort. This effort was intended to provide an initial Systems Model for UST waste remediation cost estimation.

Appendix

Fig. 8-10	Hanford #	Fig. 8-10	Hanford #	Fig. 8-10	Hanford #
1	A101/SST	60	BX109/SST	119	SY101/DST
2	A102/SST	61	BX110/SST	120	SY102/DST
3	A103/SST	62	BX111/SST	121	SY103/DST
4	A104/SST	63	BX112/SST	122	T101/SST
5	A105/SST	64	BY101/SST	123	T102/SST
6	A106/SST	65	BY102/SST	124	T103/SST
7	AN101/DST	66	BY103/SST	125	T104/SST
8	AN102/DST	67	BY104/SST	126	T105/SST
9	AN103/DST	68	BY105/SST	127	T106/SST
10	AN104/DST	69	BY106/SST	128	T107/SST
11	AN105/DST	70	BY107/SST	129	T108/SST
12	AN106/DST	71	BY108/SST	130	T109/SST
13	AN107/DST	72	BY109/SST	131	T110/SST
14	AP101/DST	73	BY110/SST	132	T111/SST
15	AP102/DST	74	BY111/SST	133	T112/SST
16	AP103/DST	75	BY112/SST	134	T201/SST
17	AP104/DST	76	C101/SST	135	T202/SST
18	AP105/DST	77	C102/SST	136	T203/SST
19	AP106/DST	78	C103/SST	137	T204/SST
20	AP107/DST	79	C104/SST	138	TX101/SST
21	AP108/DST	80	C105/SST	139	TX102/SST
22	AW101/DST	81	C106/SST	140	TX103/SST
23	AW102/DST	82	C107/SST	141	TX104/SST
24	AW103/DST	83	C108/SST	142	TX105/SST
25	AW104/DST	84	C109/SST	143	TX106/SST
26	AW105/DST	85	C110/SST	144	TX107/SST
27	AW106/DST	86	C111/SST	145	TX108/SST
28	AX101/SST	87	C112/SST	146	TX109/SST
29	AX102/SST	88	C201/SST	147	TX110/SST
30	AX103/SST	89	C202/SST	148	TX111/SST
31	AX104/SST	90	C203/SST	149	TX112/SST
32	AY101/DST	91	C204/SST	150	TX113/SST
33	AY102/DST	92	S101/SST	151	TX114/SST
34	AZ101/DST	93	S102/SST	152	TX115/SST
35	AZ102/DST	94	S103/SST	153	TX116/SST
36	B101/SST	95	S104/SST	154	TX117/SST
37	B102/SST	96	S105/SST	155	TX118/SST
38	B103/SST	97	S106/SST	156	TY101/SST
39	B104/SST	98	S107/SST	157	TY102/SST
40	B105/SST	99	S108/SST	158	TY103/SST
41	B106/SST	100	S109/SST	159	TY104/SST
42	B107/SST	101	S110/SST	160	TY105/SST
43	B108/SST	102	S111/SST	161	TY106/SST
44	B109/SST	103	S112/SST	162	U101/SST
45	B110/SST	104	SX101/SST	163	U102/SST
46	B111/SST	105	SX102/SST	164	U103/SST
47	B112/SST	106	SX103/SST	165	U104/SST
48	B201/SST	107	SX104/SST	166	U105/SST
49	B202/SST	108	SX105/SST	167	U106/SST
50	B203/SST	109	SX106/SST	168	U107/SST
51	B204/SST	110	SX107/SST	169	U108/SST
52	BX101/SST	111	SX108/SST	170	U109/SST
53	BX102/SST	112	SX109/SST	171	U110/SST
54	BX103/SST	113	SX110/SST	172	U111/SST
55	BX104/SST	114	SX111/SST	173	U112/SST
56	BX105/SST	115	SX112/SST	174	U201/SST
57	BX106/SST	116	SX113/SST	175	U202/SST
58	BX107/SST	117	SX114/SST	176	U203/SST
59	BX108/SST	118	SX115/SST	177	U204/SST

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